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Abstract
This article describes the genesis and nature of a 40-day course intended to improve the teaching of physics in England by teachers not originally trained in the subject. It also describes early experiences and discusses course evaluation. An accompanying article by James de Winter reviews experiences as described by participating teachers.

S Online supplementary data available from stacks.iop.org/physed/46/152/mmedia

Introduction

In 2004, the UK government published an economic policy document titled *Science and Innovation Investment Framework 2004–14* (HM Treasury 2004) with a ten-year strategy for producing future scientists, engineers and technologists. It recognized a continuing shortage of physics, chemistry and mathematics teachers and set a target for 25% of science teachers to have a physics specialism by 2014.

A report by the National Foundation for Educational Research (NFER 2006) indicated that, of all secondary teachers in England:

- 44% were biology specialists;
- 25% were chemistry specialists, and;
- 19% were physics specialists.

According to the Institute of Physics, this report suggested a shortage of more than 4000 physics teachers across England (Institute of Physics 2010a).

The Science and Technology Committee of the House of Lords (2006) discussed the critical importance of specialist teaching for science subjects. There was evidence that non-specialist teaching adversely affects pupil confidence, enjoyment and achievement, as well as post-16 subject choices and career choices.

A later survey, Smithers and Robinson (2008), found that almost one in four secondary schools in England no longer had any specialist physics teachers, varying regionally from 10% to 50% and averaging 40% in 11–16 schools. The general situation is aggravated by the age profile of physics-trained teachers in England and Wales, with many of them nearing retirement age. Estimated inflows and outflows of physics teachers in 2005–6 indicated that about 115 (26%) more left than entered the profession.

In a recent newsletter, Charles Tracy, Head of Education—Pre-19 at the Institute of Physics, is quoted saying England's shortage of physics teachers 'is set to get worse: we are still recruiting 400 too few new physics teachers every year' (Institute of Physics 2010b).

Against this background, there are numerous UK initiatives to support physics teaching. Prominent among these are the Institute of Physics Teacher Network (part of its Stimulating Physics Network) and short courses for non-specialist teachers of physics offered by regional Science Learning Centres (SLCs). The most significant courses in England for non-specialists, in terms

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of breadth and depth, have been the Physics Enhancement Project (Shepherd 2008) and the course described in some detail below.

Science Additional Specialisms Programme (Physics)

Following a two-year pilot, in 2009 the Training and Development Agency for Schools (TDA) set up national programmes in England to support non-specialist secondary teachers of mathematics, physics and chemistry, called the Science Additional Specialisms Programme (SASP). Anyone teaching physics in a state school without a physics degree or an initial teacher training specialism in physics, could apply to attend a 40-day course to develop their physics subject knowledge and pedagogical skills. The course involves 30 taught days, each of five hours, plus 10 days for independent study and classroom observations of expert physics teaching. In the current academic year, the SASP physics course runs at three English universities and six regional Science Learning Centres, involving about 180 teachers in total.

On successful completion, participants should be able to 'teach physics effectively, with enthusiasm and confidence, to learners aged 11–19 years in schools or further education colleges' (TDA website). This means that they need to become familiar with curriculum resources from which to construct teaching sequences and be able to make independent, professional judgements related to physics teaching and learning. They must also develop relevant practical capabilities and maths skills. Clearly this course offers a natural progression from in-school or SLC short courses, for those who want to take their physics further.

Incentives for teachers, schools and training providers

The TDA requires teachers to attend at least 80% of the taught days to pass the course. Those who successfully complete the final assessed task are awarded a Graduate Certificate in Physics Education and a bursary of £5k. Many teachers allocate additional free time to the course, taking the total time invested up to as much as 80 days.

Schools can claim cover expenses for 40 days, enabling the teacher to be taken off timetable one day weekly for a full year. Schools can benefit from significantly improved physics teaching, leading to better pupil attainment, attitudes to physics and likelihood of studying physics post-16. The SASP teacher can also

- support other non-specialist teachers in the department, possibly running workshops based on SASP course materials and activities;
- ensure that apparatus 'lurking in the cupboard' gets used;
- improve departmental schemes of work;
- suggest high-impact apparatus purchases for the department.

Training providers are able to claim for the costs of management, administration and teaching of the course, with an agreed amount paid for each SASP teacher who passes the course. The school must designate a Mentor to support the teacher and act as the school's main link with SASP staff, throughout the course.

A SASP physics tutor guide

In January 2009 the Institute of Physics commissioned me to write a Tutor Guide, one contribution to its SASP physics partnership with the national network of Science Learning Centres. In writing the Tutor Guide, a part-time task over many months, I drew on

- experiences of physics tutors involved in the SASP pilot phase;
- science education research, not only about non-specialists teachers of physics but also about common misconceptions and teaching challenges;
- my own experience, about 20 years in the classroom followed by a decade of science curriculum development and teacher training;
- suggestions and feedback from two 'critical friends', Prof Robin Millar (York University) and Dr Jenny Frost (a tutor for the Physics Enhancement Programme, mentioned above, who had recently retired from the Institute of Education, London) and from several people who had been designated to tutor SASP physics at regional Science Learning Centres during 2009–10.

Effective teaching requires a proper understanding of the learners and starts from their experience. The Tutor Guide assumed that

- many SASP teachers were likely to have been conditioned by their own experience of physics education at school level;
- some may have struggled with physics-related aspects of their degree specialism.

Non-specialists frequently say that their physics teaching is weak because they are unable to give potted histories of physics or tell physics anecdotes. Their teaching can also be limited by having no idea of what comes next for learners progressing through a physics education. Education literature (Millar 1988, Mualem and Eylon 2009) suggested that SASP teachers were likely to be anxious about getting explanations wrong in the classroom and some would admit to a fear of physics. They also tend to avoid practical work in physics, not only because unfamiliar apparatus (e.g. oscilloscope, ripple tank, Teltron tube, vernier callipers) can be intimidating but also because it is likely to provoke pupil questions which they cannot answer.

If becoming a better physics teacher was a simple matter of in-filling gaps in physics knowledge, then non-specialist teachers could do it themselves and many would. The real task for SASP physics is transformative: enabling people who view themselves as specialists in one subject to internalize and identify positively with another subject. Teaching physics with enthusiasm comes from a deep understanding and consequent appreciation of its power. Teachers would need to be actively engaged in the SASP course, supporting each other as they learn to 'think physics', an approach consistent with insights from constructivist learning theory.

The Tutor Guide also needed to embody models of both professional learning (Bishop and Denley 2007) and classroom interactions (Ogborn *et al* 1996). As many education researchers and teacher educators recognize, professional knowledge for teachers has two main components, subject knowledge and subject pedagogical knowledge. It is most important that teachers learn how to develop their pupils' understanding of physics, recognizing and responding appropriately to common misconceptions and teaching challenges.

Two publications from abroad (Knight 2004, McDermott 1996) proved particularly useful. Knight suggests the following teaching and learning strategies:

- keeping participants actively engaged and providing rapid feedback;
- focusing on phenomena rather than abstractions;
- exposing and discussing common misconceptions;
- teaching and using explicit problem-solving skills;
- setting homework and exam problems that go beyond symbol manipulation to engage participants in the qualitative and conceptual analysis of physical phenomena.

The SASP course covers most concepts encountered from ages 11 to 18, contextualizes them in appropriate ways, and even suggests how some of them develop at undergraduate level. Concepts are presented in a sensible order, going as deep as possible at every stage so that later topics can revisit and build on solid foundations of knowledge and skills. For example, an understanding of Newton's laws underpins kinetic theory and the behaviour of ideal gases. Going further, Galilean relativity, mechanical waves, electric fields, magnetic fields all need to be covered too before introducing electromagnetic waves and special relativity.

'Big picture' ideas about physics also need to feature regularly: length and timescales; the importance of modelling (Hestenes 1987); major explanatory strands such as action-at-a-distance behaviour, the nature of matter, processes and change; turning points and unifications in the history of physics.

A common mistake for the non-specialist teacher is to introduce concepts through equations, often manipulating the symbols for physical quantities using an equation 'triangle'. This convenient heuristic too often replaces understanding, undermining progression in the subject. Mualem and Eylon (2009) describe the benefits of improving learners' qualitative understanding. McDermott (1996) highlights the importance of first developing semi-quantitative understanding through proportional reasoning.

Skills explicitly developed include effective pedagogical approaches, and essential mathematics. Practical capability comes from handling apparatus and exploring experimental approaches, including datalogging, whenever appropriate.

In its final form, the Tutor Guide describes specific learning outcomes and possible activities

Table 1. Outline of the SASP physics course content.

	Indicative content	Taught days
Introduction	'Big picture' physics, comparing it to other sciences	2
Fundamentals	Forces	14–17
	Simple electric circuits	
	Waves, sound, light and the electromagnetic spectrum	
	Kinetic theory and the behaviour of gases	
	Energy and energy resources	
	Magnetism and electromagnetism	
	Radioactivity	
Advanced	Mechanics in 2D, circular motion and SHM	11–14
	Waves in 2D	
	DC circuit theory	
	Electric, gravitational and magnetic fields	
	Quanta: atomic, nuclear and particle physics	
	Exponential processes	
	Astronomy and cosmology	
	Thermodynamics	
Concluding	'Big picture' and course review	1
		Total 30

for 35 possible days. An outline of the course content is shown in table 1. After a short introduction, physics concepts are grouped into thematic clusters at two levels, fundamental and advanced. This enables tutors to devise a 30-day-course to match the needs of their participants.

The Guide was used by lead tutors in all three SLC regions offering SASP physics in 2009–10 and is currently used in the six SLC regions offering SASP physics in 2010–11. Some SASP tutors choose to develop all concepts within a theme before moving on; others use a spiral approach, developing fundamental concepts in the first half of the course before moving on to advanced level. As a courtesy, in 2009 the Guide was also sent to tutors at the three SASP physics providers outside the SLC network, but they may not have implemented it.

Learning in groups

The regional SASP physics providers each recruit between 15 and 26 teachers, bringing to each course a very broad range of backgrounds, teaching experience, physics knowledge and ability. Generally a small number are already teaching physics at A-level and all teach physics across the age range 11–16. Many register for the course with a view to becoming 'teacher in charge of physics' at their school.

Adjusting to being in the role of adult learner can be an unexpected challenge. An early priority for tutors is getting the teachers to mix and work together, varying the groupings and helping to establish a positive attitude to many kinds of challenge. Gradually a group identity emerges and participants look forward to their days together. Each Science Learning Centre also has its own online course area, where participants can access course-related materials and communicate among themselves. The teachers are expected to read and refer to textbooks in their own time.

Throughout the course year an important task for the teachers is to keep a reflective learning journal, recording for example

- responses to what happens on the course each week;
- significant developments in their subject knowledge;
- impact of SASP-inspired pedagogical approaches on pupil learning;
- how pupil responses affect their own learning;

This helps to give teachers ownership of their learning and encourages deeper learning as they make more connections.

A typical SASP day

A SASP taught day at one of the Science Learning Centres will generally include short lectures incorporating practical demonstrations, a session in the laboratory, a session doing practice

questions, and plenary sessions. Teachers very often work in pairs or small groups and are encouraged to ask questions as they arise. There is always a lot of discussion, as teachers identify points of confusion, experience physical processes and practice doing physics with a tutor present to help and give feedback.

It is important that the SASP course itself models good classroom practice. Learners typically vary in their interests and preferences. SASP days implicitly demonstrate a variety of teaching approaches needed in school classrooms, though some activities devised for teachers need to be adapted to work with pupils.

An extract from the SASP Physics Tutor Guide is available to download (available in the online journal at stacks.iop.org/physed/46/152/mmedia), a day with the theme 'Kinetic theory and the behaviour of gases'. To illustrate how a tutor fleshes out the Tutor Guide outline, the extract is accompanied by resources created for the London interpretation of this particular day.

Diagnostic tests, formative and summative assessment

At the start and end of the course, participants do a diagnostic test consisting of about 30 multiple choice questions, to assess their understanding of key physics concepts. These are intended to assess areas of strength and weakness, motivating study. The diagnostic tests also inform SASP tutors as they plan teaching and learning activities.

During the course there are three written assignments, which must all incorporate insights from science education research. In the first term, teachers compare how they introduce a topic in their specialist subject with how they introduce a physics topic. In the second term they plan, teach and evaluate a sequence of three physics lessons. In the final term, they plan a scheme of work for an A-level physics topic and also draw on journal entries to reflect on their learning journey. The first two assignments are formative and the third is summative. Teachers must pass the final assignment in order to qualify for the TDA bursary.

Feedback from participants

Several times during the course, the teachers complete course evaluations. They can comment on each part of the course, in terms of its overall quality, their personal interest and enjoyment, the extent to which it meets their needs for subject knowledge, pedagogical knowledge and practical capability. They can also describe what has been most useful and most enjoyable, and make suggestions about how the course could be improved. Together with informal feedback, the course soon begins to feel like a collaborative endeavour between tutor and participants, an exciting and not altogether predictable adventure into new territory.

In London, twice during the year the teachers also complete a self-evaluation form, which they discuss with their school mentor and jointly sign before handing over to the course tutor. For each topic they rate their start and end points, on an arbitrary scale of 1–10, in respect of subject knowledge, understanding of teaching challenges, suitable teaching approaches, practical capability and maths skills. The 2009–10 cohort did the exercise twice, evaluating their progress with the whole course. At the time of writing, the 2010–11 cohort has only done the exercise for the first part of the course ('fundamentals'). With both cohorts, a few participants did not return the form. Results are shown in table 2.

In the 'fundamentals' part of the course, London teachers scored their improvements most highly for forces and electric circuits. This is consistent with both the initial SASP diagnostic test results and also earlier research (Millar 1988). Unsurprisingly, participants generally scored their improvements at advanced level more highly than improvements in fundamentals.

London teachers commonly state that studying 'fundamentals' enabled them to confront and correct their own misconceptions, giving new confidence and secure foundations on which to build knowledge associated with advanced topics. This year more attention is being given to maths skills, after complaints from some 2009–10 teachers that developing maths skills did not have a sufficient profile.

As part of the self-evaluation exercise, the London teachers also reflect on their own study efforts, learning in groups and how able they are to meet school needs. On a five-point Likert scale, almost all teachers indicated that they either 'strongly agree' or 'agree' with three statements:

- 'Other teachers on the course contribute to my learning.'

Table 2. Average teacher improvement, indicated on an arbitrary ten-point scale, declared in London self-evaluation exercises.

Topic	Subject knowledge	Practical capability	Maths skills	Understanding of teaching challenges	Suitable teaching approaches
Fundamentals ($n = 42$)					
Forces	2.71	2.86	1.74	2.74	2.69
Earth in space	2.10	1.90	1.33	1.71	1.81
Electric circuits	2.38	2.45	1.52	2.20	2.31
Waves, sound and light	1.98	2.29	1.48	2.05	2.32
Advanced ($n = 16$)					
Mechanics	3.06	3.44	2.31	3.38	3.13
DC circuits	2.94	3.06	2.63	3.19	3.38
Waves and fields	3.13	3.38	2.75	3.13	3.25
Modern physics	3.38	2.81	2.25	3.06	3.56

- ‘I am able (or will be able) to improve the school’s schemes of work, using what I’m learning on the course.’
- ‘I am able (or will be able) to suggest items of equipment for the school to acquire, to improve the teaching of physics.’

Experiences as a course tutor

Across the regions, SASP physics course tutors come from quite a variety of backgrounds. All have previous experience of training and supporting science teachers, including non-specialist physics teachers. Even with a Tutor Guide giving shape to the course, new tutors have typically devoted two days of preparation time for each day of teaching, to ensure that activities and print materials suit their particular teacher cohort.

During the year, lead tutors at the SLCs meet face-to-face a few times and otherwise communicate by e-mail, comparing notes, exchanging resources and discussing common issues. All tutors comment on the challenges of teaching large groups with disparate starting points and particular learning needs. Collaborative learning is really the only way that such an extensive and complex course can be effective. In my experience, this certainly helps the tutor avoid any temptation to overdo the lecturing mode. It also makes it essential to get to know participants personally and always to welcome questions and discussion.

Responding to the particular needs and interests of participating teachers is of paramount importance. Course tutors have been unstinting in their efforts to make the course work, sustained by thanks from participating teachers, repeatedly expressed. None of us has ever before experienced the pleasure of having time to explore physics in such depth with non-specialists. A chief reward is generating new understanding and enthusiasm, both for physics as a subject and for teaching physics.

What happens after completing the course?

Teachers who have successfully completed the course would certainly benefit by ongoing support so that they continue to develop as physics teachers, especially when they begin teaching physics at A-level. Sadly the TDA does not fund any formal follow-up to the 40-day SASP courses.

Some informal collaborative learning may continue: many teachers exchange e-mail addresses and so can communicate privately, as well as through the online SASP physics course area. In practice, however, teachers are preoccupied by pressing day-to-day tasks, after returning full time to the classroom. This makes it difficult to communicate with anyone outside their own school about aspects of physics teaching.

In London, there are plans for a one-day course to review, 12 months later, progress towards SASP-related targets which the teachers set for themselves on the final day of their course; however, we do not yet know whether the schools will support an unfunded follow-up, enabling teachers to attend.

Evaluating the course

In summer 2010, 64 teachers completed the SASP physics course at three regional Science Learning

Centres. Of these, all except one was awarded a Graduate Certificate in Physics Education and the TDA bursary. National data on numbers subsequently teaching A-level physics this year are not available, but I know that it includes about one third of the London cohort.

Oral and written feedback from all participants testifies to the positive impact which the course has had on the teachers' confidence and competence in teaching physics. It also demonstrates that, in many cases, classroom practice has dramatically changed for the better and pupils of all ages are more engaged in physics lessons. Do read James de Winter's article in this same issue (de Winter 2011), which contains many quotes from teachers.

In recent years, we have been learning a lot about the needs of non-specialist teachers and how best to help them become effective physics teachers. What we do not yet know is how the course may impact in the longer term on SASP teachers and, indirectly, on their teacher and technician colleagues and on their pupils. The many early indicators of success described above suggest an urgent need for evaluative research into all aspects of this remarkable course.

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Weblinks

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